EUV Lithography
Transition from Research to Commercialization

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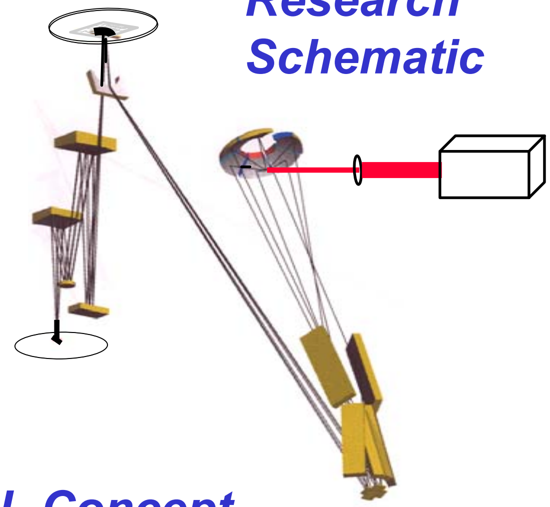
EUV Lithography
Transition from Research to Commercialization

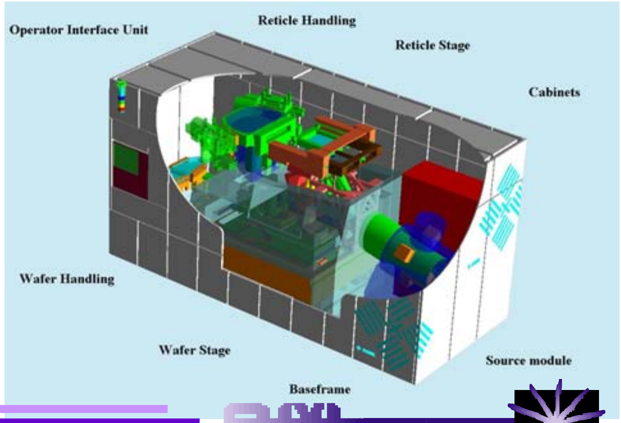
Outline

- Background
- Technology Description
- Research results and status
- Commercialization status
    - Source
    - Tools
    - Masks
- World wide focus
- Remaining challenges
- Summary

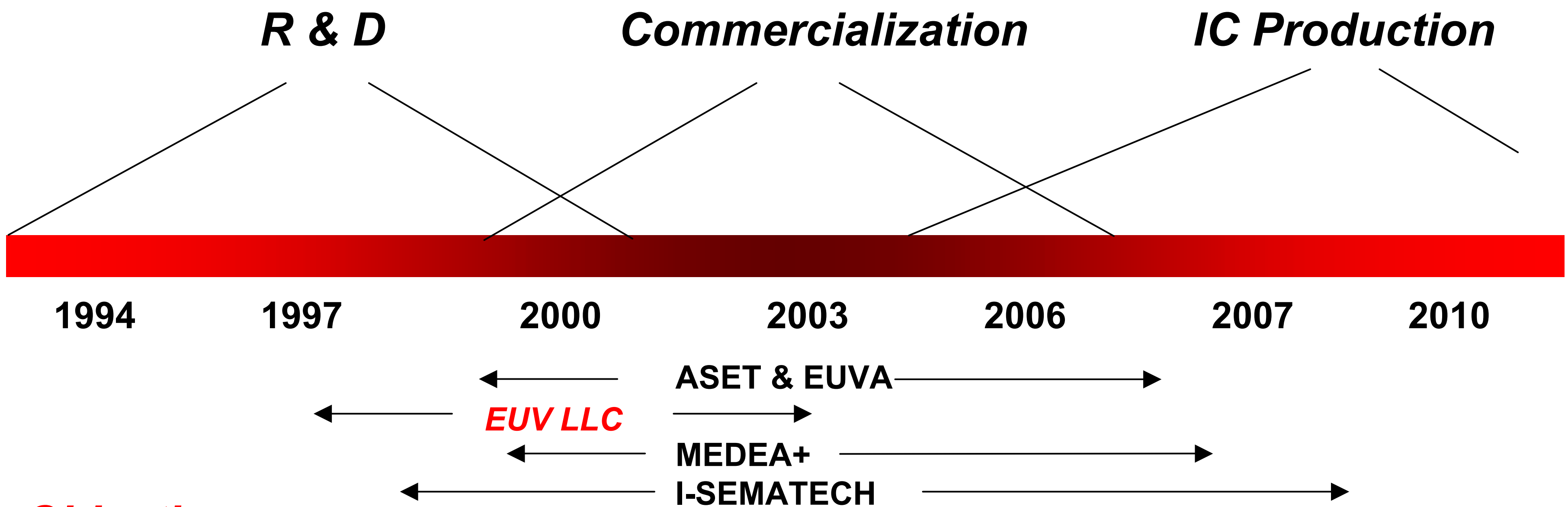
Research Schematic



ASML Concept



Phases of EUVL implementation



Objectives

- Perform basic R & D
- Develop and integrate modules into alpha tool
- Demonstrate EUVL printing & quantify needed improvements

- Develop beta and preproduction tools
- Implement improvements with selective R&D
- Establish infrastructure for masks, resists, and Metrology equipment

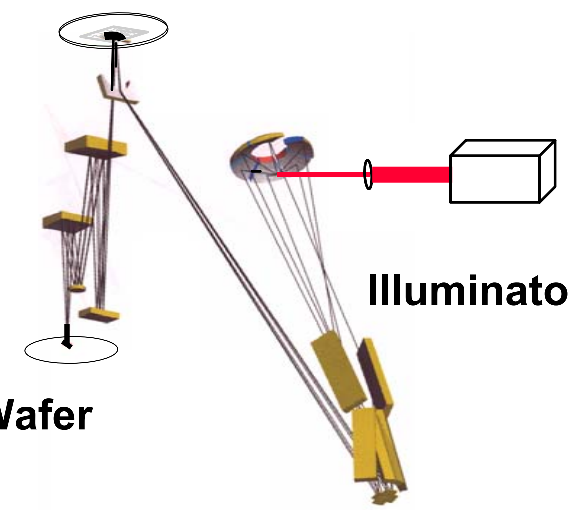
- Manufacture production tools
- Scale up infrastructure
- Continuous improvement

EUV LLC Research and Development

Strategy

Develop the unique modules required for EUV Lithography:

- **Reflective Projection Optics and Condenser**
- **EUV Source**
- **Environmental Control Systems**
- **Mask Blanks and Masks**
- **Resist**

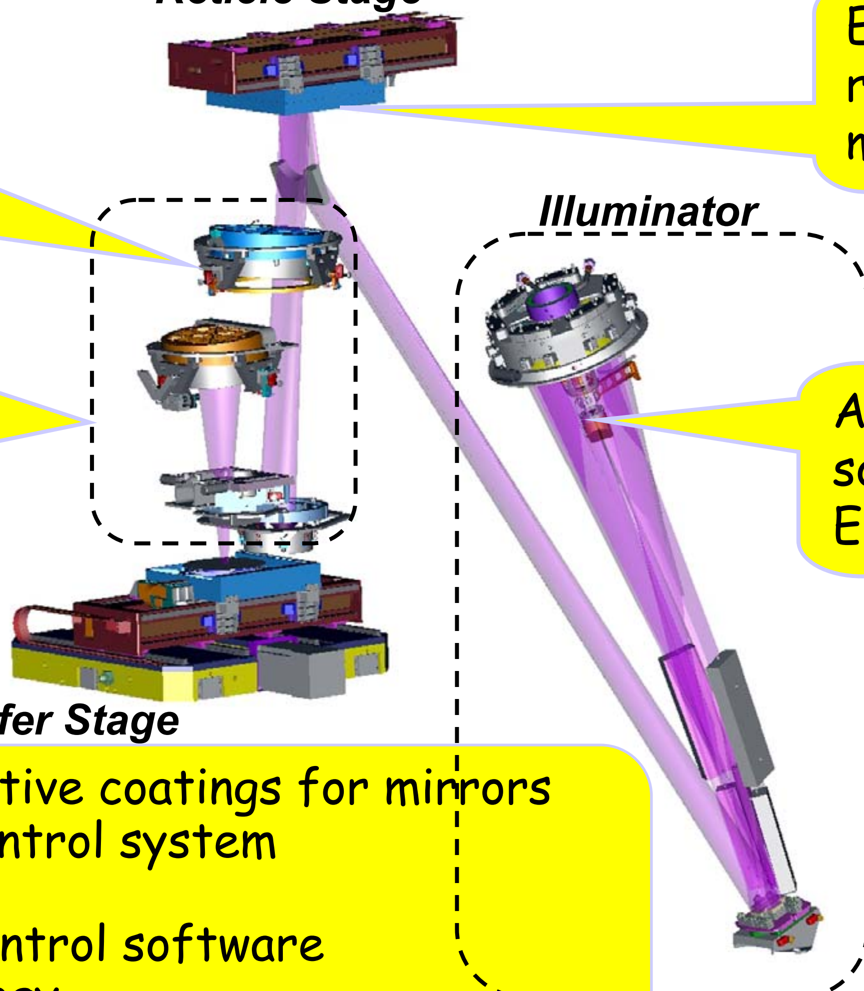


Goal
Demonstrate the feasibility of EUV Lithography by building a prototype 100nm EUV Lithography exposure tool

EUVL R & D requirements different than conventional lithography

Aspheric mirrors with sub-nm surface error

Robust 4X reduction EUV reflective projection optics



EUV reflective masks

A reliable source of EUV photons

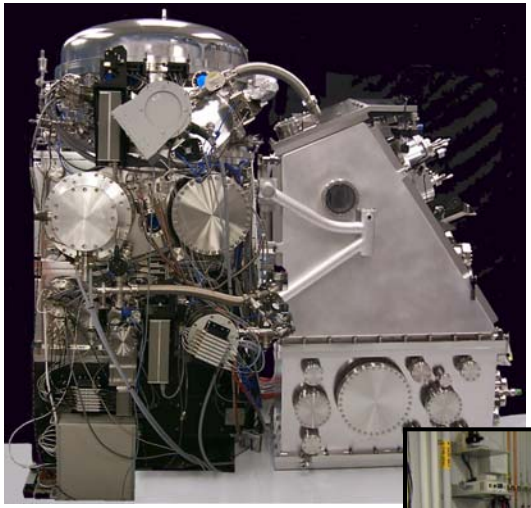
A condenser to collect and shape EUV radiation

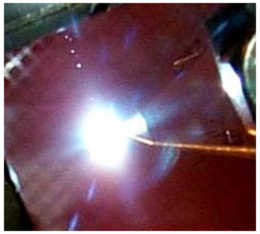
- Multilayer reflective coatings for mirrors
- Environmental control system
- EUV resist
- Operating and control software
- Precision Metrology

Modules integrated into demonstration alpha tool

Reticle Stage

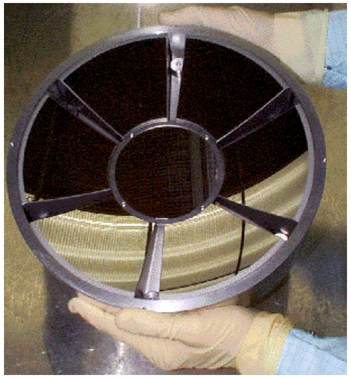
Engineering Test Stand



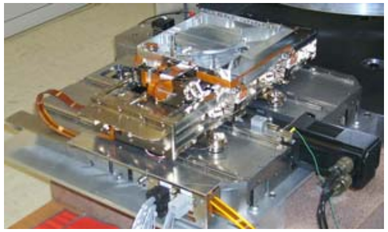


Laser Plasma Source

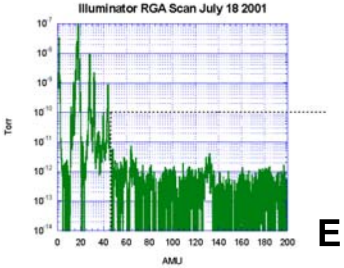
PO Box



Condenser Optic



Wafer Stage

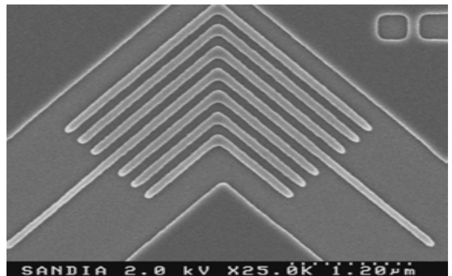


Environment Control

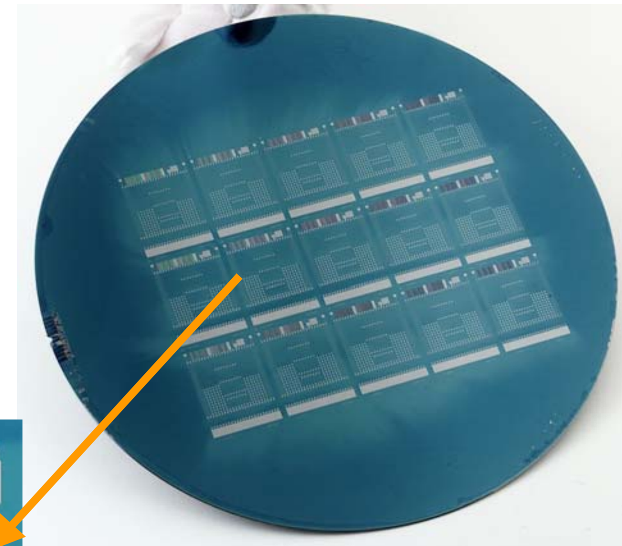
Control & Data Acquisition

Full field Images produced by 0.1 NA ETS

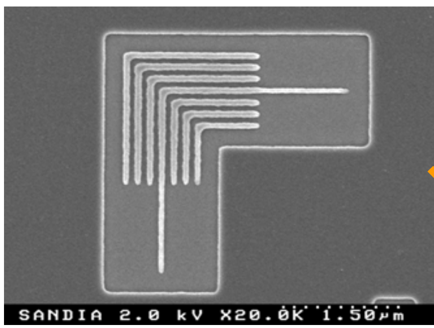
100 nm Elbows 1:1

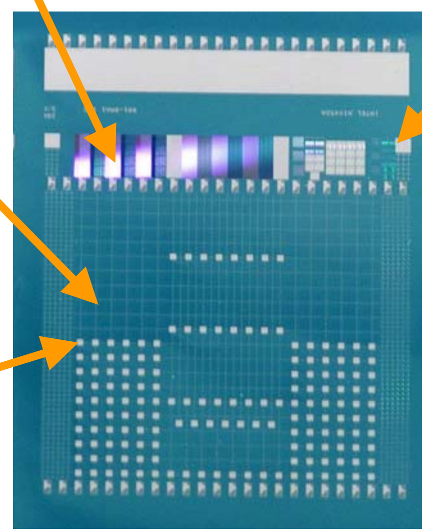


200 mm Wafer

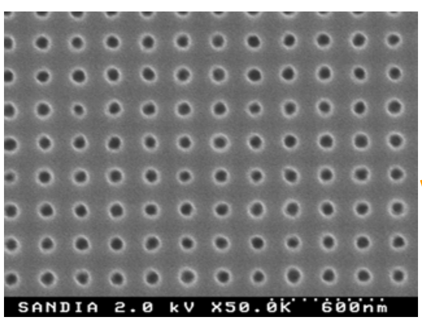


80 nm Elbows 1:1





100 nm contacts 1:1



24 x 32.5 mm^2 field

R & D Exposure Systems

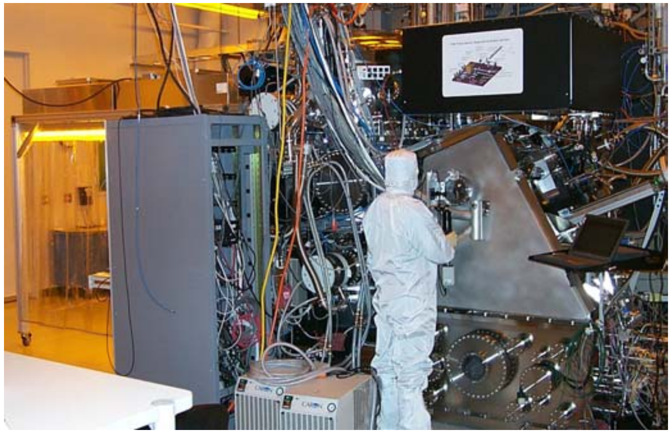
System (type)	Location	NA/ Magnification	Field size Min. Res.	Lens quality	Reticle Size
ETS Scanner	Livermore, CA	0.1 4 x	24 x 32 mm^2	$\lambda/20$	6 inch sq.
10x Microstepper	Livermore, CA	0.1/10 x	0.5 x 0.5 mm	$\lambda/40$	1.25 x 1.06 in wafer
BESSY MET static	Berlin, Germany	0.3/5x	200x600 $microns^2$	$\lambda/10$	8 inch wafer
BEL static	Grenoble, France	0.3/10x	100x200 microns	$\lambda/10$	8 inch wafer 6 x 6 inch reticle
ASET static	Atsugi, Japan	0.3/5x	300 x 500	$\lambda/7$	8 inch wafer
MET (static)	Berkeley, CA	0.3/5x	200 x 600	$\lambda/40$	6 inch reticle

Other capabilities include a 10x interferometric exposure capability at Berkeley and at the U. of Wisconsin

R & D Status

Technology:

- All elements of technology demonstrated
    - Full field scanning alpha tool
    - Mask fabrication & repair
    - Experiments correlate with models
    - Metrology for optics and masks
- Key decisions made, e.g. wavelength, mask format, engineered multilayers, etc.
- Tools are available for continued learning



R & D activity:

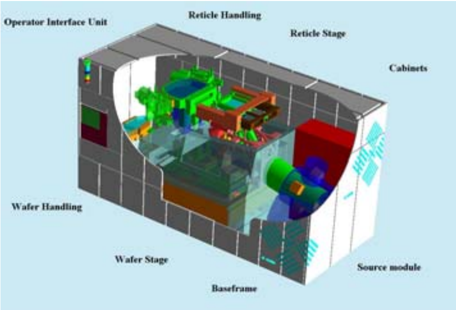
- VNL available for technology transfer
- Individual LLC members continuing selective R & D
- Universities actively pursuing projects
- I-SEMATECH establishing Mask Development Center in Albany, NY

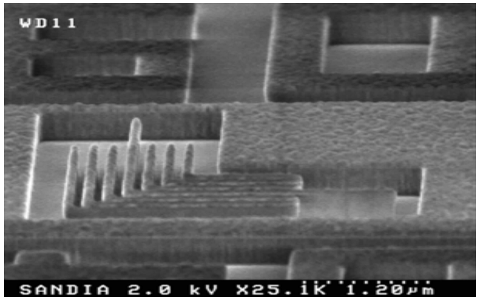
Needs:

- Continued improvement for all areas and reduced CoO

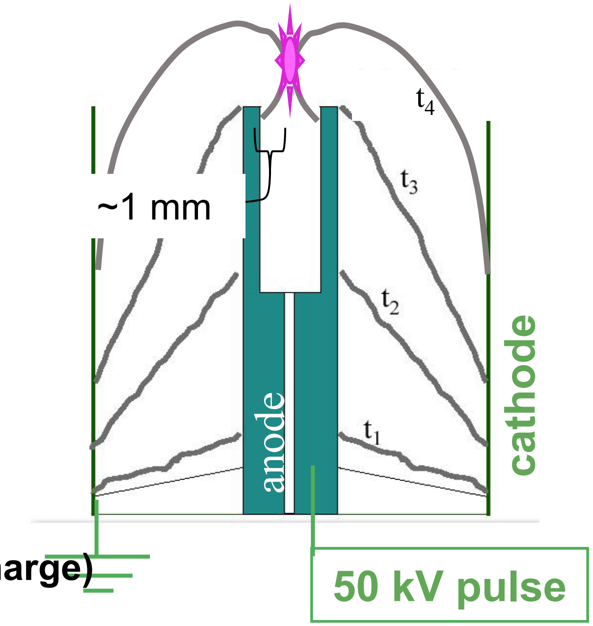
Commercialization focusing on three areas

- Tools
  - EUV Source
    - Discharge
    - Laser Plasma
  - Beta tools
    - Microstepper
    - Stepper scanners
- Masks
  - Blanks
  - Patterned masks
  - Metrology
- Resists





Electric Discharge Source



Technology:

- Pulsed electrical discharge creates plasma in presence of Xe gas
- Plasma-wall proximity increases thermal and erosion problems

- Collected EUV power = Input electrical power / (collector efficiency)(wall to discharge)

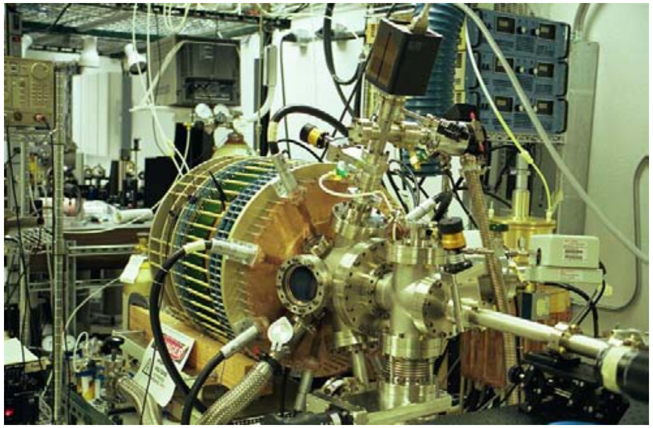
- Up to 17 W at intermediate focus @ 6kHz burst mode
- Issues: Electrode lifetime and debris
- Sn considered as alternate to Xe target

Commercial status:

- Systems operating only in burst mode
- Leading systems: Cymer, Xtreme, Philips

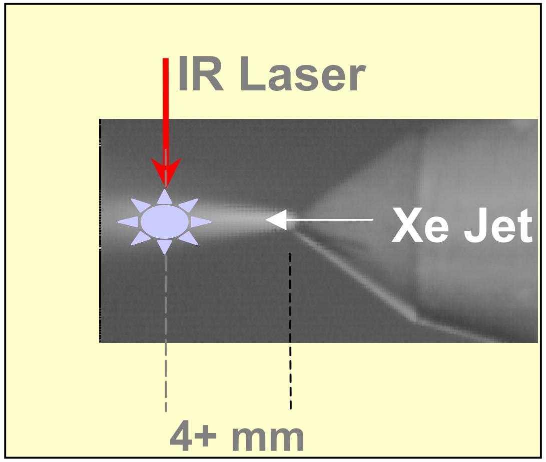
Production Needs:

- Higher power, multiplexed sources
- Improved conversion/collection efficiencies
- Improved CoO



Cymer DPF System

Laser-Produced Plasma Source

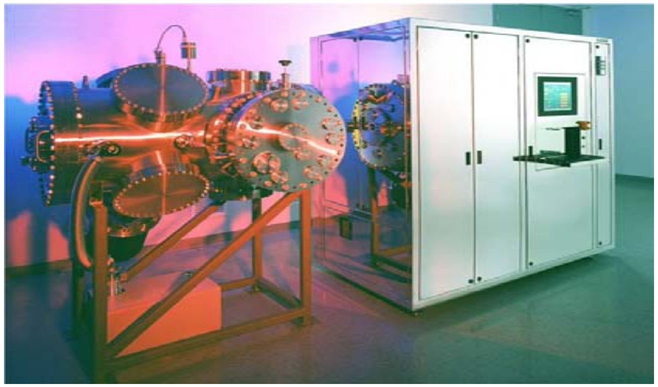


Technology:

- Pulsed IR laser focused on Xe gas, liquid or solid target creates plasma
- Good plasma-wall separation: helps thermal erosion
- Relatively inefficient EUV generation (multiple steps)
- Collected EUV power = Input electrical power / (collector efficiency)(laser to EUV)(wall to laser)
- Sn being considered as alternate for Xe target

Commercial status:

- Leading system: CEO/TRW
  4.5 KW LPP laser developed, 3 chains tested,
  22 W EUV in 2π with filament jet, 9.4 W, 0.87% eff.,
  at intermediate focus with 2.4 KW laser
- Active development for 6 systems by Japanese, European, and US companies
- Sn considered as an alternate target

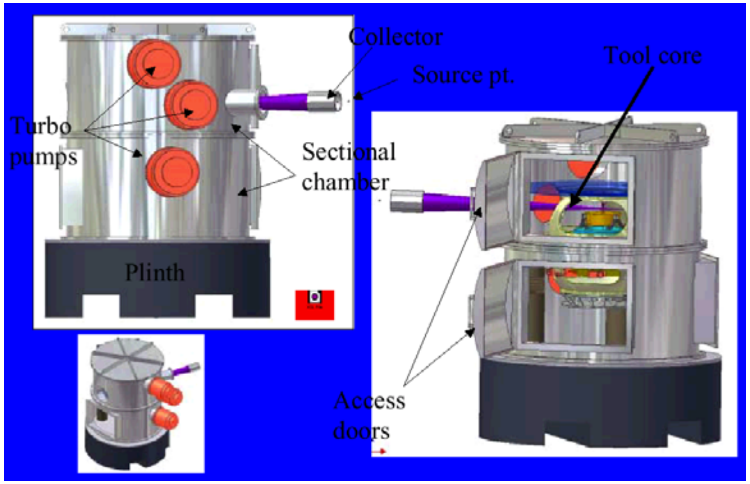


CEO 4.5 KW System

Production Needs:

- Higher power
- Improved conversion/collection efficiencies

Exposure EUVL tools

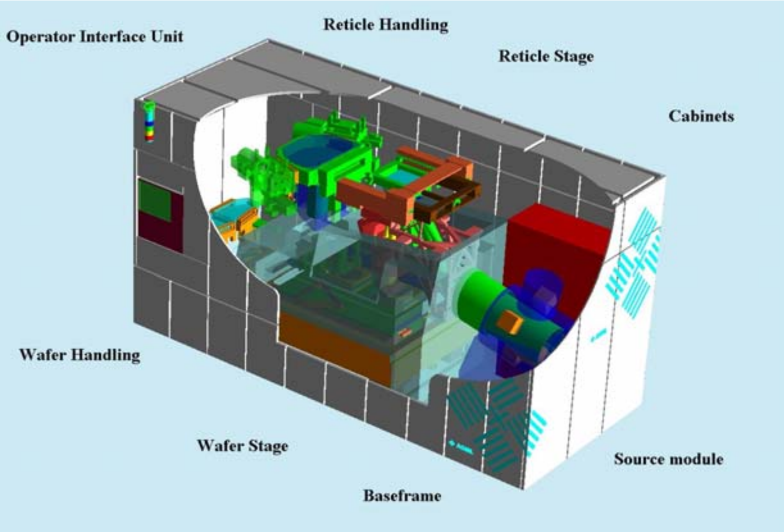


Technology:

- Complete tools validate technology feasibility - ETS and other R & D tools,
- All modules/processes demonstrated – optics, multilayers, metrology, stages, vacuum operation

Commercial status:

- Exitech developing 0.3 NA microsteppers for process development – deliveries in 04
- ASML, Nikon and Canon developing beta and production tools
- Over 100 companies and laboratories working on subsystems and components



Production Needs:

- Accelerated schedule for tools
- Additional infrastructure suppliers

Mask Development

Strategy:

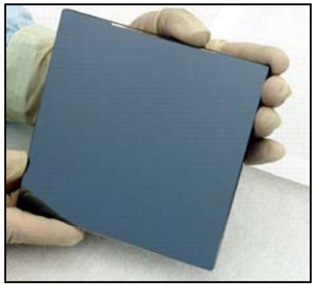
Mask Blanks

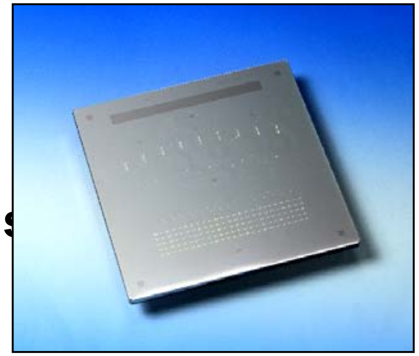
- **Use LTEM polished blanks**
- **Cover and repair defects**
- **Deposit low defect multilayers**
- **Inspection and repair defects**
- **Absorber deposition**

Mask Patterning

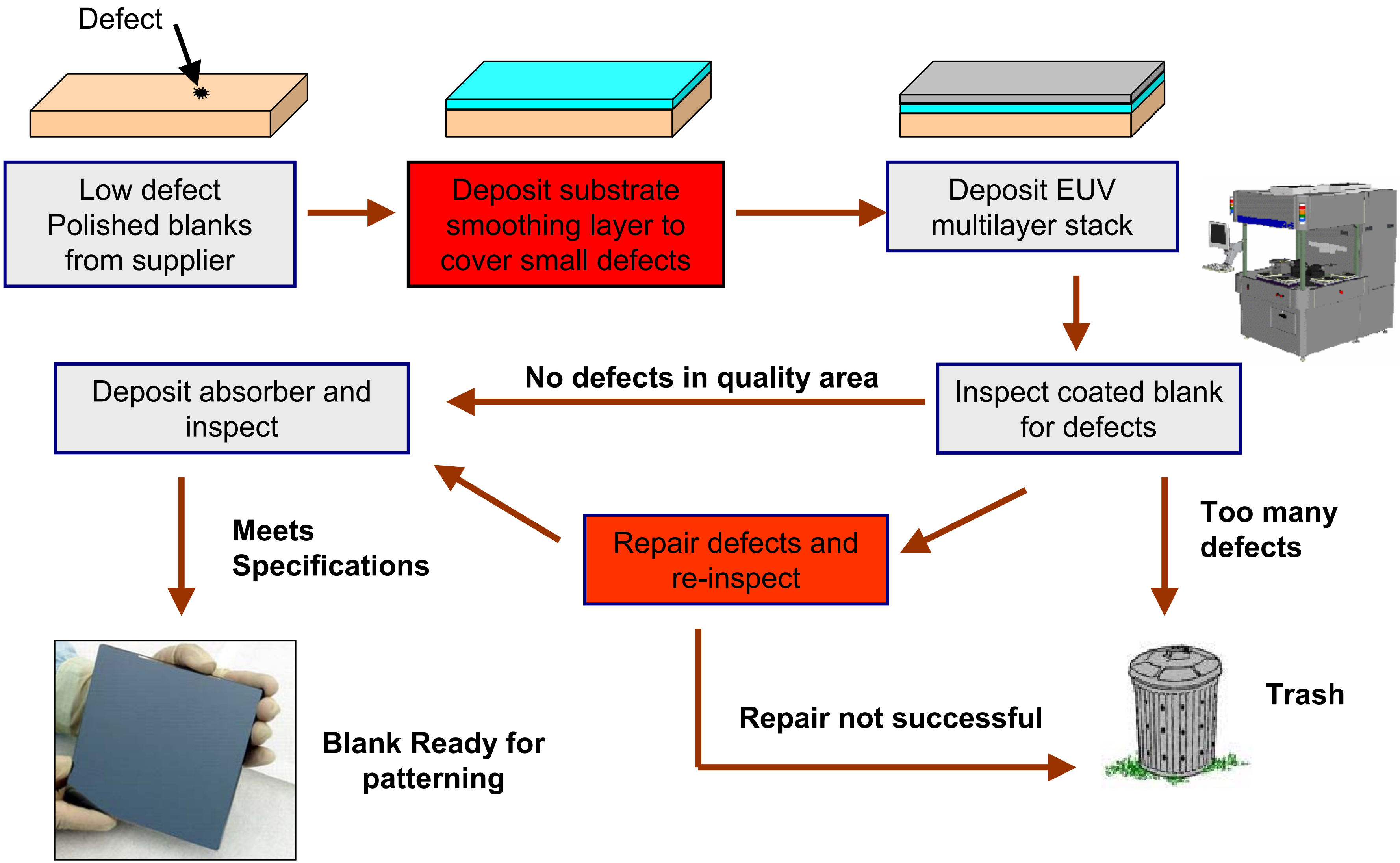
- **Use conventional ebeam writing**
- **Extend/adapt conventional inspection tools**
- **Use FIB pr ebeam for repair**
- **Use removable protection cover**

Affordable mask costs



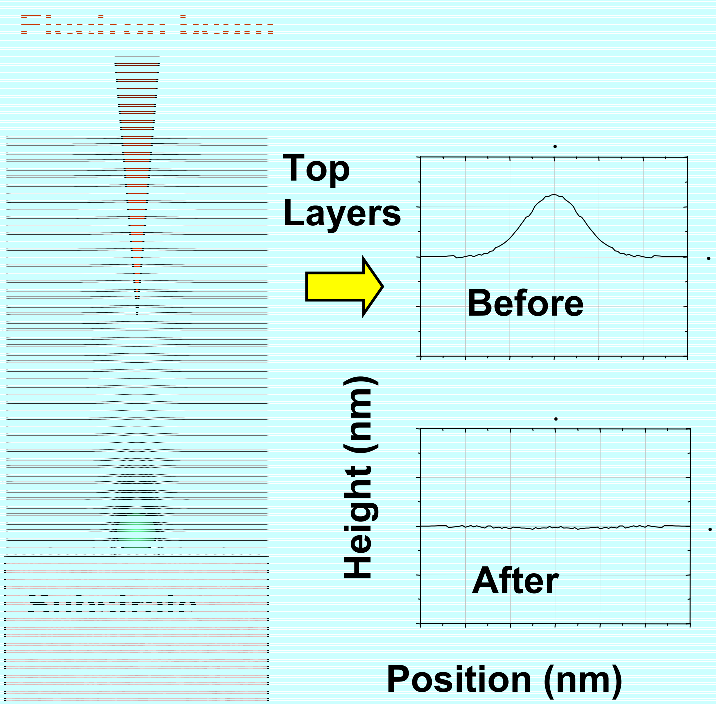


Mask blank manufacturing process



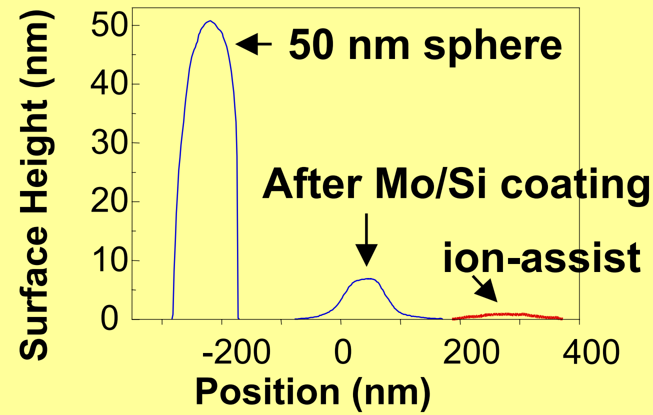
Mask Blank Defect Repair

Phase defect repair

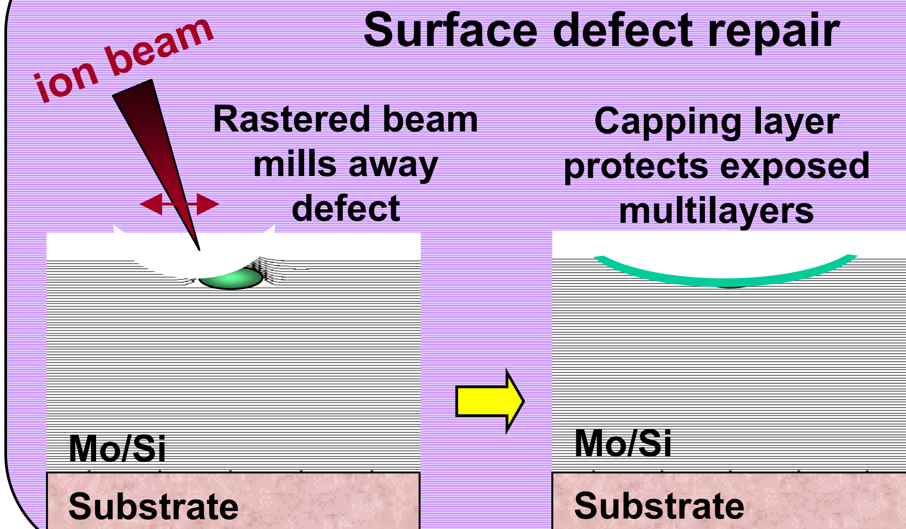


Localized heating and ML contraction controlled by adjusting e-beam dose

Substrate defect smoothing



Surface defect repair



Mask Blank production

Technology;

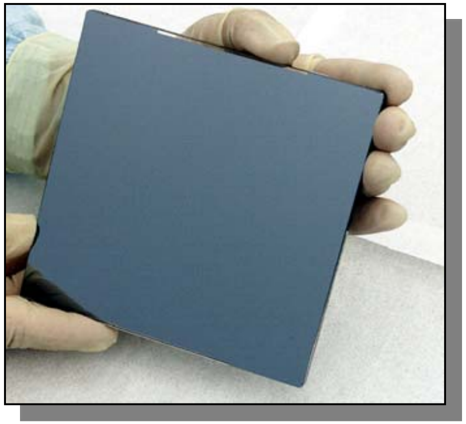
- LTEM or Zerodur materials - SEMI standard P37
- Blanks polished to <200 nm flatness
- Models developed and applied for stress, flatness, and chucking effects
- LTEM mask materials identified and characterized
- Defect mitigation and repair methods developed

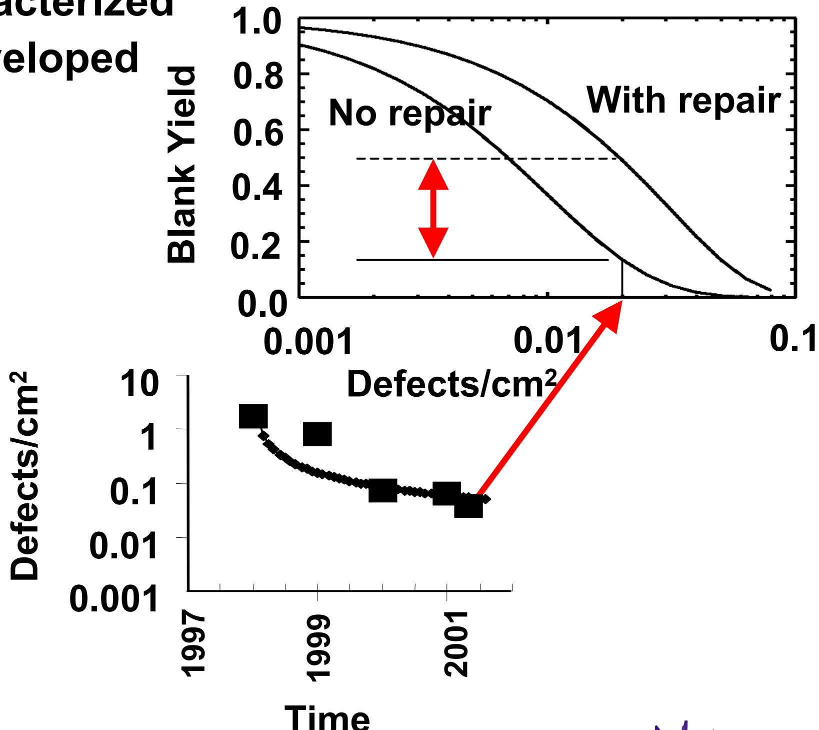
Commercial status:

- Schott Lithotech, Asahi, Hoya, Corning developing blanks
- I-SEMATECH establishing mask blank development center in Albany, NY

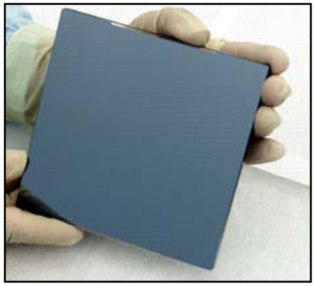
Production needs:

- Improved blank flatness – 50 nm
- Combined inspection/repair tool
- Reduced costs





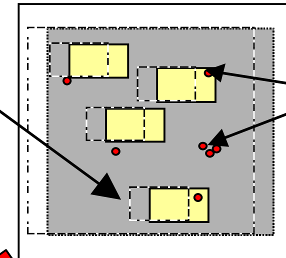
Mask patterning steps



Mask blanks from supplier

Deposit resist and prebake

Shift Mask Pattern to Cover one or more defects



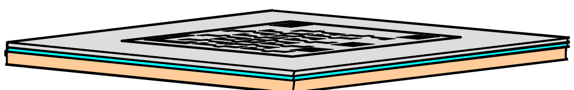
Mask Blank defects

E-beam write, Etch & Clean

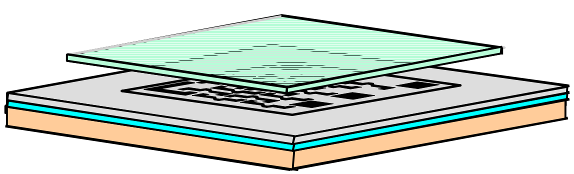
Inspect patterned masks

Repair masks using FIB or ebeam

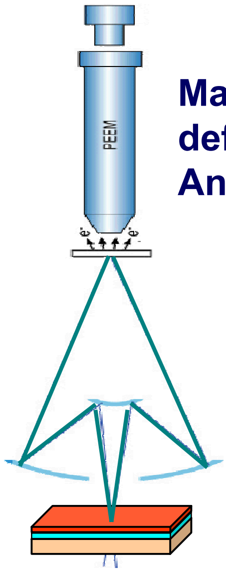
Final inspect & clean



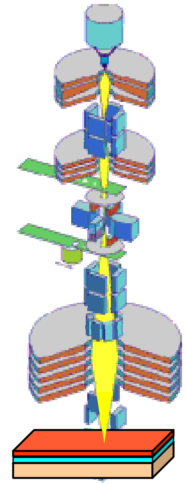
Mount in frame with removable protective cover



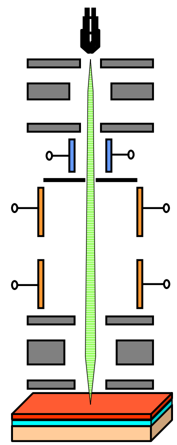
Patterned mask inspection and repair



Mask microscope for
defect classification
And inspection



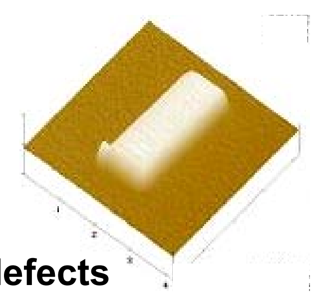
Conventional FIB
metal deposition
or removal



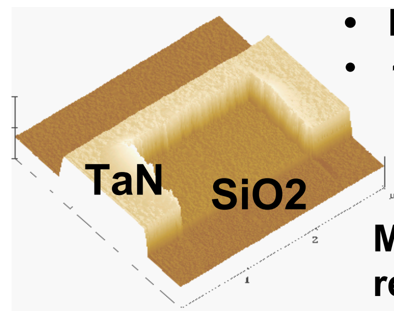
Electron beam
pattern repair

Electron-Beam Mask Repair

- Eliminates Ga ion stains
- No ion-beam damage
- High etch selectivity
- Minimizes buffer layers
- ~ 30 nm resolution



Metal deposition
for clear pattern defects

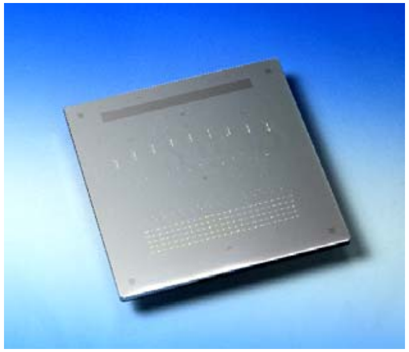


Metal pattern
removal

Mask Patterning

Technology;

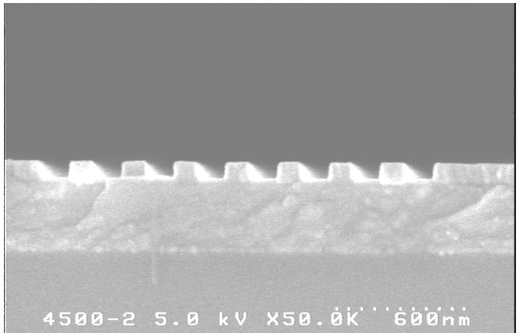
- Variety of absorbers evaluated, Cr and TaN preferred
- Masks patterned using commercial e-beam writing tools
- Two Mask SEMI standards approved, two in process
- Inspection tools demonstrated
- Repair demonstrated using Ga FIB and e-beam etching
- Large k1 minimizes need for OPC, simple flare compensation
- Removable pellicle/cover proposed



152 mm^2, 4X Dark Field Reflective Masks

Commercial status:

- Masks produced by:
  - Company mask shops:
    Intel, Motorola, AMD, IBM, and Infineon
  - Mask companies: RTC, MCoC, DPI
- Standards developed



120 nm lines/spaces

Production needs:

- Inspection and repair equipment
- Continued development of removable pellicle

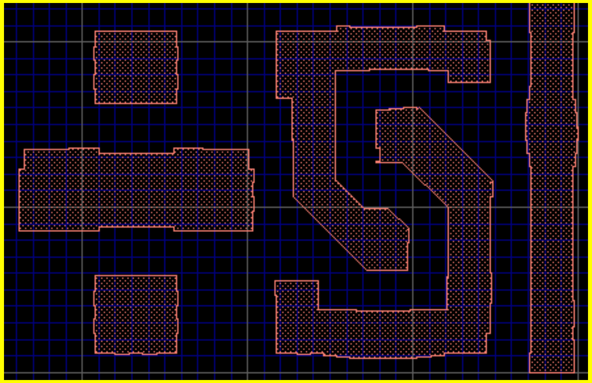
Estimated EUV & Optical Mask Costs for 45 nm

	Key Attributes	EUV cost relative to optical	
Mask blank	flat/defect free	similar Specs.	1.0
Multilayers	multilayer coated	more layers	1.2
Defect inspection	DUV inspection	similar/phase	1.2
Writing time	ebeam, similar CD's	less complex	0.5 – 0.6
Pattern Insp.	DUV inspection	simpler	0.6 – 0.7

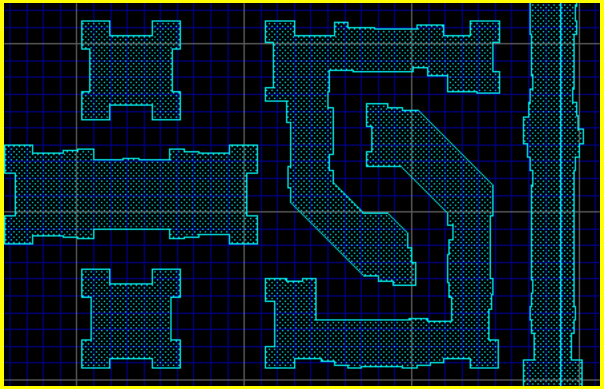
Estimated costs for 45 nm (equivalent process maturity)

Optical - OPC only		$ 100 k
	OPC & complementary	$ 150 k
EUV		$ 43 - $90 k

EUV mask



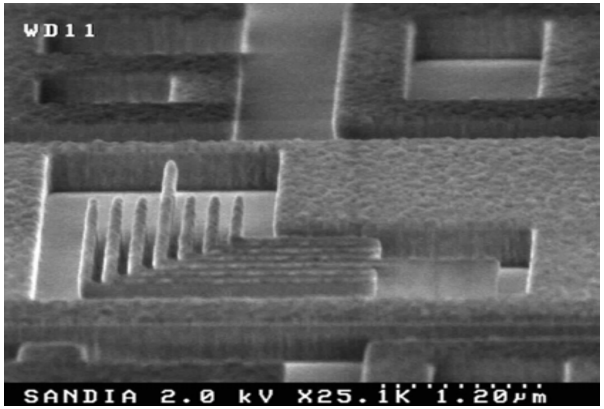
Optical Mask with OPC



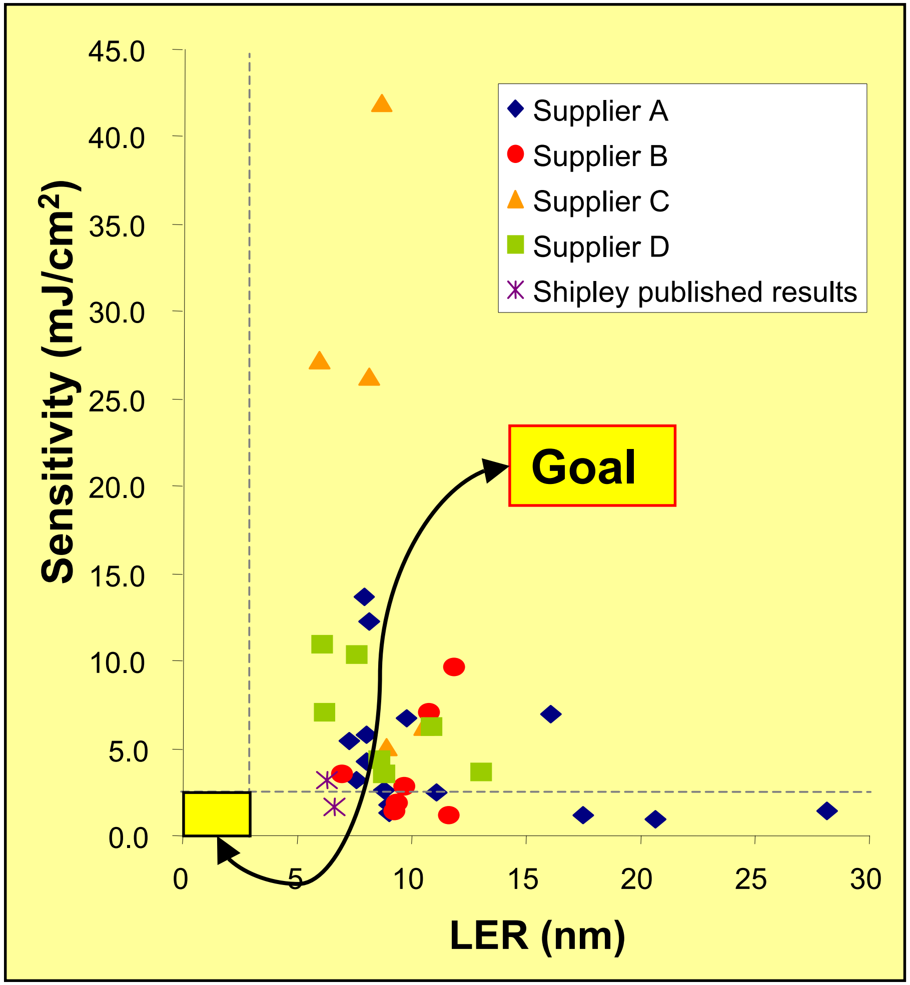
Resists

Approach

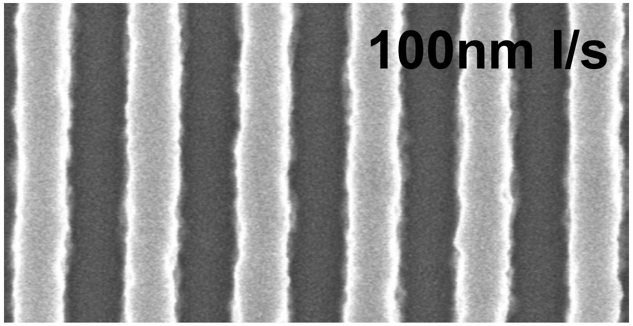
- Extend chemically amplified deep UV resists
- Use Ultra thin resists (UTR)
- Evaluate single layer and bilayer resists



Resist LER Needs Improvement

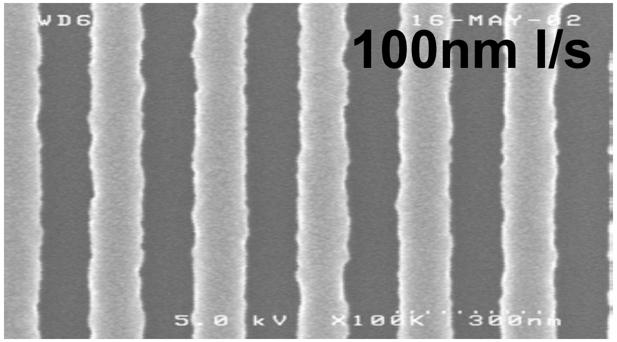


Best positive resist



Dose=2.3 mJ/cm^2 LER=7.2 nm

Best negative resist

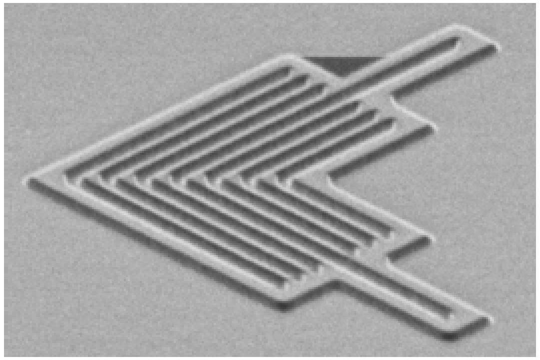


Dose=3.2 mJ/cm^2 LER= 7.6nm

Resist Development

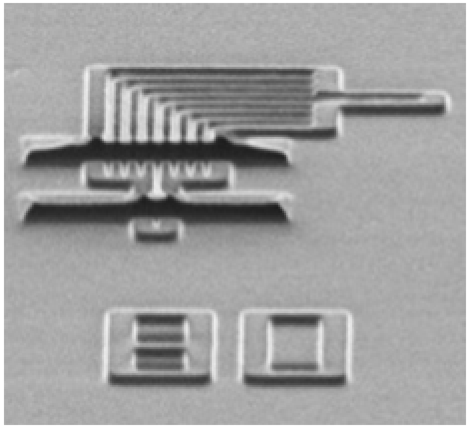
Technology;

- Both single layer and bilayer resists demonstrated
- DUV ultra thin resists viable > 85 nm
- Resist sensitivities demonstrated down to ~ 2.0 mJ/cm^2 , LER 5 – 7 nm
- Pattern transfer into hard masks demonstrated
- Flare understood - compensation methods available



Commercialization status:

- Companies actively developing resists Shipley, JSR, TOK



Production Needs:

- Reduced LER and improved sensitivity

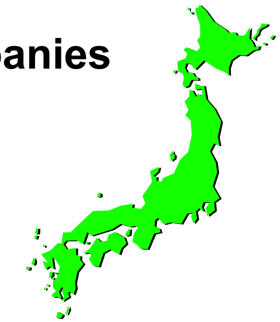
World wide EUVL commercialization focus

Japan

> 10 Companies

Consortia:

- **ASET**
- **EUVA**
- **MIRAI**



Europe

> 50 Commercial Cos.

Consortia:

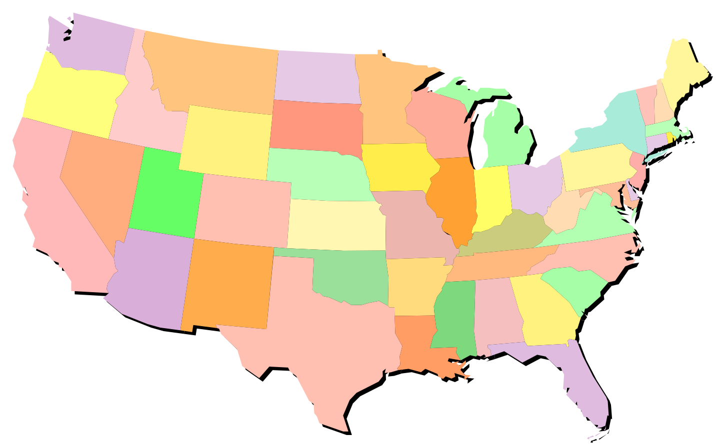
- **PREUVE**
- **MEDEA+**
- **LETI**
- **IMEC**

US

> 40 Commercial companies

Consortia:

- **EUV LLC**
- **I-SEMATECH**
- **VNL RDC**
- **SRC**



Remaining challenges

Lithography tools with acceptable CoO	Present	Required
Beta tool schedule	2006 - 2007	2005 -2006
Source Output (at intermediate focus)	< 10 Watts	>100 Watts
Optics/Illuminator lifetime	TBD	>5 Yrs/>1 Yr
Optics figure and finish	~25 nm rms	<14 nm rms
Multilayer reflectivity (optics)	~65%	>70 %
Production throughput – 300 mm wafers	------	>80 wph

Resists

LER (3σ)	7 nm @ 2.5 mJ	3 nm @ 2.5 mJ
Resolution/Sensitivity (Printing/dose)	40 nm/5 mJ	<20 nm/2.5 mJ

Masks

Blank flatness	200 nm	50 nm
Blank defect levels (@50 nm)	0.04/cm^2	0.003/cm^2
Inspection (blanks and patterned wafers)	70 nm defects	30 nm defects
CD measurements	70 nm	30 nm

Summary

EUVL is the only viable solution for 45 nm

- **Integration of all EUVL modules demonstrated feasibility of the EUVL technology**
- **Mask costs are affordable – defect mitigation and repair methods demonstrated**
- **Suppliers are engaged to commercialize the technology**
- **Remaining technical challenges have been identified and are actively being addressed**
- **Commercialization emphasis is required**